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HERMANN VON HELMHOLTZ[1]

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THE history of science concerns itself with the historical and logical sequence of scientific concepts. The process of development by which man arrives at fundamental laws of the universe in which we live is a vital study, having great possibilities for furthering the advance of science. Studies in this field have shown that the part of particular individuals, even men of great genius, is much less than is commonly supposed. Advance in science rests upon the work of many individuals whose observations and reflections cover rather long intervals of time. The genius is that fortunate individual who arrives upon the scene when the accumulation of observations enables the formulation of some general law for whose reception and acceptance the way has been prepared. The genius "reaps where others have sown"; the genius is great, as Newton intimated, because he stands upon the shoulders of giants.

Obviously only few men can be successful in attaching their names to fundamental laws. Prominent in this group is Hermann von Helmholtz, who in 1847 at the age of twenty-six, gave a complete statement of the law of the conservation of energy. Good fortune came his way in this law of energy and more than once again, but it must be said that Helmholtz met good fortune more than half-way, and entertained her so royally that no one could dispute his right to the visitation.

Helmholtz was favored, also, in living to see the law of the conservation of energy accepted as a truism, to see this law made the basis of the researches of hundreds of able scientists, and in being able himself to devote nearly half-a-century of vigorous intellectual activity to problems intimately connected with his first success. Towards the very end of his life in 1894, the great German was working upon the similar but more inclusive "principle of least action" which he hoped to extend mathematically so as to apply to all forces of nature.

Helmholtz applied rigorously to biological problems the methods of physical science and mathematical reasoning. His activity marks the beginning of the period in which philosophical speculation about science was definitely superseded by experimental research in science, combined with mathematical treatment of the observations. The law of the conservation of energy was stated by him with a wealth of illustrations from mechanics, electricity, heat and biology, but it also included a mathematical formulation and discussion of the problem. In the study of physiological optics and of light, in the study of sound and harmony and the ear, in the study of the psychology of the senses, in the study of vortex motions, in the study of electrical phenomena and of physics generally, Helmholtz constantly reinforced experimental work with rigorous mathematical demonstration. Were one to attempt to characterize in a few words his extraordinary range of researches, one would say that Helmholtz brought biological and physical problems under the dominion of mathematical formulas and methods.

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[1] A paper read at a meeting of the Research Club, University of Michigan, April 20, 1921, in commemoration of the centennials of Hermann von Helmholtz and Rudolph Virchow.

The rôle of the mathematical formulation and treatment of physical problems can not be overestimated. Kelvin, the intimate friend and active co-worker in science with Helmholtz, has stated: "All great scientific discoveries are but the rewards of patient, painstaking sifting of numerical data." With these data the scientist starts, making fundamental assumptions in the mathematical formulation of the problem. The successful formulation explains on the basis of the fundamental assumptions the observed facts; further than this, the procedure places the observed facts in harmony with other apparently widely-diverse phenomena, showing the harmony of natural forces and the reign of law in nature. But more than this the mathematical formulation suggests new facts of observation, and permits the prediction of observations which had previously escaped the observer. This is the peculiar merit, for example, of the Einstein theory, that it explains the facts of the Newtonian universe, explains certain facts which were in conflict with the Newtonian theory and enables the theorist to predict other natural effects not consonant with the Newtonian theory and hitherto unobserved. This type of mathematical ability Helmholtz had in a surprising degree, and it made possible his contributions to the advancement of science.

In a centennial recognition of a life of such great significance for mankind, the purpose is both historical and inspirational. What is the historical setting of the contributions of Helmholtz to civilization? What were the circumstances of birth and training, of academic position and environment, which made possible the wonderful productivity in apparently diverse fields of science? What can we do to foster the production of such men and to encourage this type of devotion to pure science? This brief survey of the life and activity of Helmholtz is prepared from the point of view of these questions.

Hermann von Helmholtz was born in Potsdam, August 31, 1821. His father was a teacher of philology and philosophy in the Potsdam gymnasium, while his mother was a lineal descendant of William Penn. Despite a certain frailty of body his preparatory work included not only the traditional classical course with Latin, Greek and Hebrew, but also English and Italian, privately, with a beginning of Arabic, together with serious training in music. Even in the schoolroom he found further time for experimental work in physics and science. At the age of sixteen, although then desiring to devote himself to physics, he took an examination for a scholarship in the Royal Frederick William Institute of Medicine and Surgery, since the financial status of his family made desirable the election of the surer means of livelihood in medicine. One year later, Helmholtz entered upon the strenuous five year course of the institute. Here he completed the regular work, and studied, while acting as librarian, the works of Euler, Daniel Bernoulli, d'Alembert and La Grange. His thesis, "The Structure of the Nervous System in Invertebrates," contained the announcement that the nerve-fibers originate in the ganglion cells found by Von Ehrenberg in 1833; this discovery has been regarded by some physiologists as the histological basis of nervous physiology and histology.

For one year Helmholtz acted as house surgeon at the Charité in Berlin and then for five years at Potsdam as army surgeon as required of graduates of the institute. During these six years, he maintained active scholarly relationships with his teacher Müller, and with his intimate school friends, Brücke and du Bois Reymond, physiologists of later repute.

At this time the vitalistic theory was still dominant in physiology. Müller proposed the problem as to the nature of the vital force, whether self-engendered or similar to those of the inorganic world. This study of "vital forces" and the formulation given to the problem by Liebig, the chemist, stimulated the young student to several studies concerned with animal heat and with vitalistic problems. During these six years Helmholtz acquired further familiarity with mathematical physics and chemistry, made necessary by the problems he was considering. It was in this period, in 1845, that the Physical Society was founded by du Bois Reymond, Brücke, Karsten, Knoblauch, Beetz and Heintz, and Helmholtz became one of the most active members with many contributions, published in the *Fortschritte der Physik.*

On July 23, 1847, Helmholtz read before the Physical Society his paper, "Die Erhaltung der Kraft." This paper was offered to Poggendorff's *Annalen,* but rejected by Gustav Magnus, the physicist, since he regarded experimental and mathematical physics as separate departments. In fact, Magnus warned Helmholtz "against undue partiality for mathematics, and the attempt to bring remote provinces of physics together by its means."

Despite the peculiar objection of Magnus, unfortunately shared by many physicists of that day, the article was published and received the enthusiastic support of a chosen few who recognized the relationship to the work of earlier mathematical physicists.

In 1848, Helmholtz received the appointment as lecturer in anatomy at the Academy of Art and assistant in the Anatomical Museum of Berlin, in recognition of his researches, and a year later was called to Königsberg as professor of physiology.

In 1885, Helmholtz became professor of anatomy and physiology at Bonn, where he remained but three years, being called in 1858 to Heidelberg as professor of physiology. In 1871, at the age of fifty, he received the call as professor of physics to Berlin, having at that time incidentally made contributions to physics comparable in both range and worth with those made by any other physicist of the same period. In 1888, Helmholtz was relieved of teaching to devote himself entirely to the Physico-technical Institute of Berlin of which he became the first president. In this office the great scholar continued until his death in 1894.

The first fruits of his lectures at Königsberg on the physiology of the sense organs was the invention, late in 1850, of the opthalmoscope, an instrument which renders it possible to examine the retina of the living eye. Helmholtz says:

> While preparing my lectures I hit upon the invention of the opthalmoscope, and then on the method of measuring the velocity of nervous impulses. The opthalmoscope became the most popular of my scientific achievements, but I have already pointed out to the oculists that good fortune had more to do with it than merit. I had to explain the theory of the emission of reflected light from the eye, as discovered by Brücke, to my students. Brücke himself was but a hair's breadth off the discovery of the opthalmoscope. He had only neglected to ask himself what optical image was formed by the rays reflected from the luminous eye. For his purpose it was not necessary to put this question. Had it occurred to him, he was just the man to answer it as quickly as I, and to invent the opthalmoscope. I was turning the problem over and over, and pondering the simplest way of making it clear to my audience, when I came on the further issue.

The opthalmoscope established the position of Helmholtz in the scientific world. More than that, opthalmic medicine had a new birth with this instrument and with the opthalmometer which Helmholtz perfected for measuring the physical constants of the eye. Many students were drawn to this field, although his description of the opthalmoscope, published in 1851, was somewhat slow in general acceptance because of the mathematical and physical knowledge pre-supposed. Helmholtz himself stated:

> I attribute my subsequent success to the fact that circumstances had fortunately planted me with some knowledge of geometry and training in physics among the doctors, where physiology presented a virgin soil of the utmost fertility, while, on the other hand, I was led by my acquaintance with

the phenomena of life to problems and points of view that are beyond the scope of pure mathematics and physics.

With both the opthalmoscope and the opthalmometer, thorough familiarity with mathematical physics was absolutely essential in the theory and construction of the instruments.

His inaugural lecture "on the nature of human sense-perceptions" was delivered at Königsberg on June 28, 1852. This discussion involved, in connection with the study of sensations of sight, problems of the theory of knowledge; it also involved an exposition of the undulatory theory of sound and light, including the statement that light rays and heat rays are identical, impinging on two different kinds of nerve end organs.

For more than fifteen years, Helmholtz worked intensively on physiological optics and his "Handbuch der Physiologischen Optik" (1856-66), marks an epoch in the physiology of the eye, in the physiological-psychology of sensations and perceptions of sight, and in the physical theories of light and color. To-day the current issue of the "Handbuch" is published with four editors to present adequately the varied fields mentioned. To particularize further his numerous contributions to optics would take more time than is at my disposal. It may be of interest to the many sufferers from astigmatism to know that this condition was discovered by Helmholtz with his opthalmometer; the defect is that the cornea and crystalline lens are not accurately centered, preventing the sufferer from seeing vertical and horizontal lines with equal clearness at the same time.

The "Handbuch der Physiologischen Optik" will long remain as one of the most noteworthy contributions made to physiological psychology, not alone from the strictly physiological and the psychological sides, but quite as much because of the comprehensive grasp of geometrical and physical properties of light and lenses as related to the physiological structure of the eye and the sensations communicated to the brain.

The notion that sensations of light and color are only symbols for relations of reality, giving no knowledge of the real nature of external phenomena, was one fundamental conclusion of these researches on optics. The wide interest in this subject induced Helmholtz to investigate the subjectivity of sensation for the other senses, beginning with acoustics. In this field the physicist, Ohm, has suggested "that the ear analyses and hears the motions of the air in exact correspondence with Fourier's series." This theorem of Fourier states that any periodic function of a variable may be expressed as the sum of periodic sine functions, of x and integral multiples of x, or, in other words that any repeating wave form may be decomposed into a number of simple waves of different length, the longest of the same length as the given wave and the others of one half, one third, one fourth, and so on, integral portions of this length. This application of a mathematical theorem to a physiological process was in such harmony with the preceding work of Helmholtz that no surprise is occasioned by his extension and development of the idea. Particularly the application of this theory to harmony was an outstanding contribution made by Helmholtz. Consonance, he taught, is produced when the ear perceives as a continuous sensation tone movements that are regularly repeated at given intervals; on the other hand, discontinuous sensation gives dissonance. Mathematically he demonstrated that vibrations in the ratio of small integers give rise to movements regularly repeated. The place of resonance and of the upper partial tones in the theory of consonance and of sound was definitely established by mathematical methods with most ingenious mechanical devices for making these upper partials evident to an observer. So far as the physiological structure of the ear is concerned, his theory was that the fibers of the basilar membrane act like the strings of a piano, and furnish the instrument of analysis into simple tones. Here, in this field the text-book which he wrote was again the result of a series of contributions to the theory of sound, based commonly upon mathematical formulation of the problems involved.

In mathematical physics proper, probably the most noteworthy contribution is that of 1857 "On the integrals of the hydrodynamic equations which express vortex-motion." The treatment both from the mathematical and the physical point of view is still fundamental in the discussion of the motions of fluids. Another paper of 1859 treats "the theory of aerial vibrations in tubes with open ends," in which from purely theoretical considerations he deduces the relations between the plane waves of the tube and hemispherical waves that spread from the tube, solving the problem of the influence of the open end upon the sound and determining the necessary lengths[2]. Kelvin elaborated the theory of vortex motion, the indestructibility of the vortex furnishing an approach to a theory of the constitution of the matter.

The electrical researches of the later years came at a period when fundamental changes in point of view were preparing. Helmholtz had accepted and furthered Maxwell's electro-magnetic theories and his gifted pupil, Hertz, achieved the experimental confirmation of the Maxwell theory, leading to the development of wireless telegraphy. Helmholtz was not only receptive to the new ideas, but active in their dissemination. In his Faraday lecture of 1881, he definitely propounded the atomistic theory of electricity now commonly accepted, which is intimately connected with fundamental chemical problems. Several studies on the thermodynamics of chemical processes followed, and the Helmholtz-Gibbs equation is to-day the fundamental theorem in this field.

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[2] It is of some interest to know that Steinway worked in the laboratory of Helmholtz during the time of Helmholtz's researches on sound. One of our own Michigan professors, Watson, the astronomer, sat on the jury of award at the Paris Exposition where the Steinway piano was given first place largely because of its superiority from the scientific standpoint. (This note is supplied to the writer by Professor A. A. Stanley.)

Helmholtz recurred so frequently in popular lectures and in scientific papers to the conservation of energy that it seems desirable to discuss the historical setting of this contribution. Particularly also, since an acrid controversy arose over the question of priority in statement. Englishmen to-day commonly credit an Englishman with the first statement, while the Germans, with better right in this case, credit a German, Robert Mayer. This arouses popular interest; many more people can comprehend the theft of an idea than can comprehend the idea. Particularly to follow the genesis of an idea requires a certain concentration which is not popular.

At the time of Helmholtz, the indestructibility of matter was accepted, apparently first started by Huygens, (1629-95). The Academy of Sciences at Paris had declined to receive any further attempts at perpetual motion since they assumed that energy could not be created. Huygens even made a general statement, in his treatise on light, that true philosophy is that "in which one conceives the cause of all natural effects as mechanical." So far as heat and energy are concerned, it is true that at this time many scientists still considered heat as a substance. However, Rumford, in 1798, showed definitely by observations on the boring of cannon that the substance theory was not tenable; Sir Humphry Davy, in 1799, clinched the argument of heat generated by friction by rubbing two pieces of ice together and generating sufficient heat to melt the ice. With Carnot, in 1824, heat was definitely recognized as a form of energy, and Clapeyron, writing in 1834 in the *Journal de l'école polytechnique* reprinted in 1843 in Poggendorff's *Annalen*, states definitely that a quantity of heat and a quantity of work are "magnitudes of like nature and that it is possible to substitute the one for the other."

The possibility of the universal application of these and other related facts to the whole field of energy was seen almost simultaneously by different observers. Robert Mayer, a German physician located in a small village, was certainly the first of this period, in 1842, to make the general statement in a paper "On the forces of inorganic nature," and he had it at first rejected by physicists of repute, and unnoticed after publication. Joule, a brewer scientist of England, in 1843 presented before the British Association a paper in which he gave the mechanical equivalent of heat, and studied relationships between electrical and chemical and mechanical effects, while in 1847, he gave the complete formulation of the principle of the conservation of energy. The formulation by Helmholtz came at a more fortunate time and place, with a richer presentation involving mathematical investigation of the fundamental considerations. But the priority of Mayer can not be disputed; nor can one dispute the great value of Joule's determination of the mechanical equivalent of heat.

A general idea of such wide significance is only possible because it is, more or less, "in the air." The idea is of value because it is definitely related to the past and to the present; the great idea must be capable of appreciation by an active group of intellectual workers, and this appreciation is only possible for an idea which has had some orderly process of growth.

Helmholtz assumes that all problems of natural science can be reduced to "unchangeable, attractive and repulsive forces whose intensity depends upon the distance. The solution of this problem is the condition for complete comprehension of nature." This assumption has within ten years been definitely rejected. Notably Albert Einstein, in a paper on "Theoretische Atomistik," and Max Planck, in a paper on "Das Prinzip der Kleinsten Wirkung," reject this conception, while retaining the greater part of the theoretical achievements of Helmholtz in his conception of the conservation of energy and the principle of least action.

Helmholtz, it should be noted, resolutely set himself against any commercialism or financial exploitation of his researches. His words on this subject are worthy of serious consideration to-day in every great American university, where in some departments a tendency exists to mix devotion to science and learning with devotion to private interests. Helmholtz says: "Whoever, in the pursuit of science, seeks after immediate practical utility may generally rest assured that he will seek in vain, . . . we must rest satisfied with the consciousness that he too has contributed something to the increasing fund of knowledge on which the dominion of man over all the forces hostile to intelligence reposes."

Helmholtz was always one of the leading figures in the academic communities in which he worked. In the German universities of that day, as in the English and European Universities of to-day, the productive scholar was given the tribute of popular recognition. No administrative officers, neither presidents nor deans, nor bursars nor secretaries, served to divert student and popular attention from the men who made the university a place of learning. In fact, the attitude towards scholarship was such that political office was tendered to Helmholtz, and every recognition the state could bestow upon an individual was given him.

One concession Helmholtz made to this popular interest, which should also be seriously considered by American scholars, particularly in our great universities. Helmholtz prepared popular expositions for general audiences of the results of his own and allied researches. These popular expositions attracted in print a great circle of readers, undoubtedly contributing to a wider appreciation and understanding of the methods and aims of science. This type of activity, so much neglected in our own universities, should be, as a university matter, a concern of the Research Club. Now it is only a matter of accident, if students of this university and citizens of this state learn what are the real contributions to human progress made within the walls of this institution. Not otherwise can a wider appreciation for true science be obtained than through the active cooperation of productive scholars.

In closing, I wish to point out how easily a man's life may be given a false interpretation by apparently competent observers. No less able a writer than W. K. Clifford states of Helmholtz that in studying the eye and ear "he found it was impossible to study the proper action . . . without studying also the nature of light and sound, which led him to the study of physics; he is now one of the greatest physicists of the century . . . . He then found it was impossible to study physics without knowing mathematics; and accordingly, he took to studying mathematics, and he is one of the most accomplished mathematicians of this century." This statement is both false and pernicious; and yet has received wide circulation and recognition. False it is because at the age of 26, and continuously for many years thereafter, Helmholtz demonstrated himself to be one of the great mathematical physicists of the world, having devoted many years to mathematical training. Pernicious it is because students are led to suppose that in later years they can atone for the neglect of their youth, and study fundamental subjects as the need arises. Helmholtz is a shining example of a man well prepared in fundamentals, whose preparation made possible for him the mathematical formulation and investigation of problems not before subjected to this analysis. His complete command of the tools prepared by mathematicians and physicists of preceding ages made Helmholtz a great contributor to modern civilization.